P. Strolin
September 2001

OPERA

Status Report

Gran Sasso detector

Emulsion Scanning

Sensitivity to oscillations

Installation and Schedule

Conclusions

Focus is on new developments

OPERA

COLLABORATION

34 groups
~ 160 physicists

Groups having joined after the Proposal are <u>underlined</u>

Belgium
IIHE(ULB-VUB) Brussels

China
IHEP Beijing, Shandong

CERN

Croatia
Zagreb

France
LAPP Annecy, IPNL Lyon, LAL Orsay, IRES Strasbourg

Germany
Berlin, Hagen, Hamburg, Münster, Rostock

Israel
Technion Haifa

Italy
Bari, Bologna, LNF Frascati, <u>LNGS</u>, Naples, Padova, Rome, Salerno

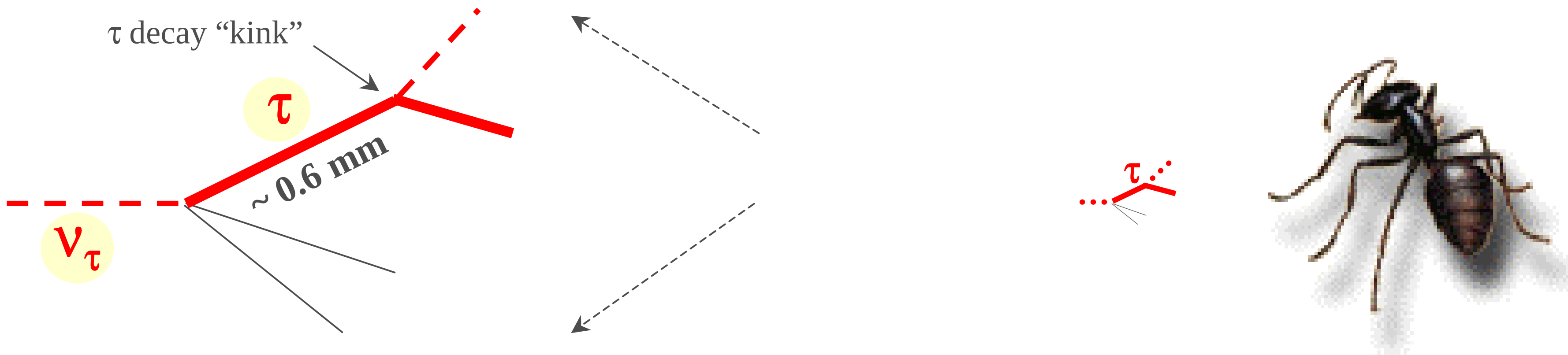
Japan
Aichi, Toho, Kobe, Nagoya, Utsunomiya

Russia
<u>INR Moscow</u>, <u>ITEP Moscow</u>, <u>JINR Dubna</u>

Switzerland
Bern, <u>Neuchâtel</u>

Turkey
METU Ankara

To identify τ leptons, “see” their decays at the <u>mm</u> scale



The challenge

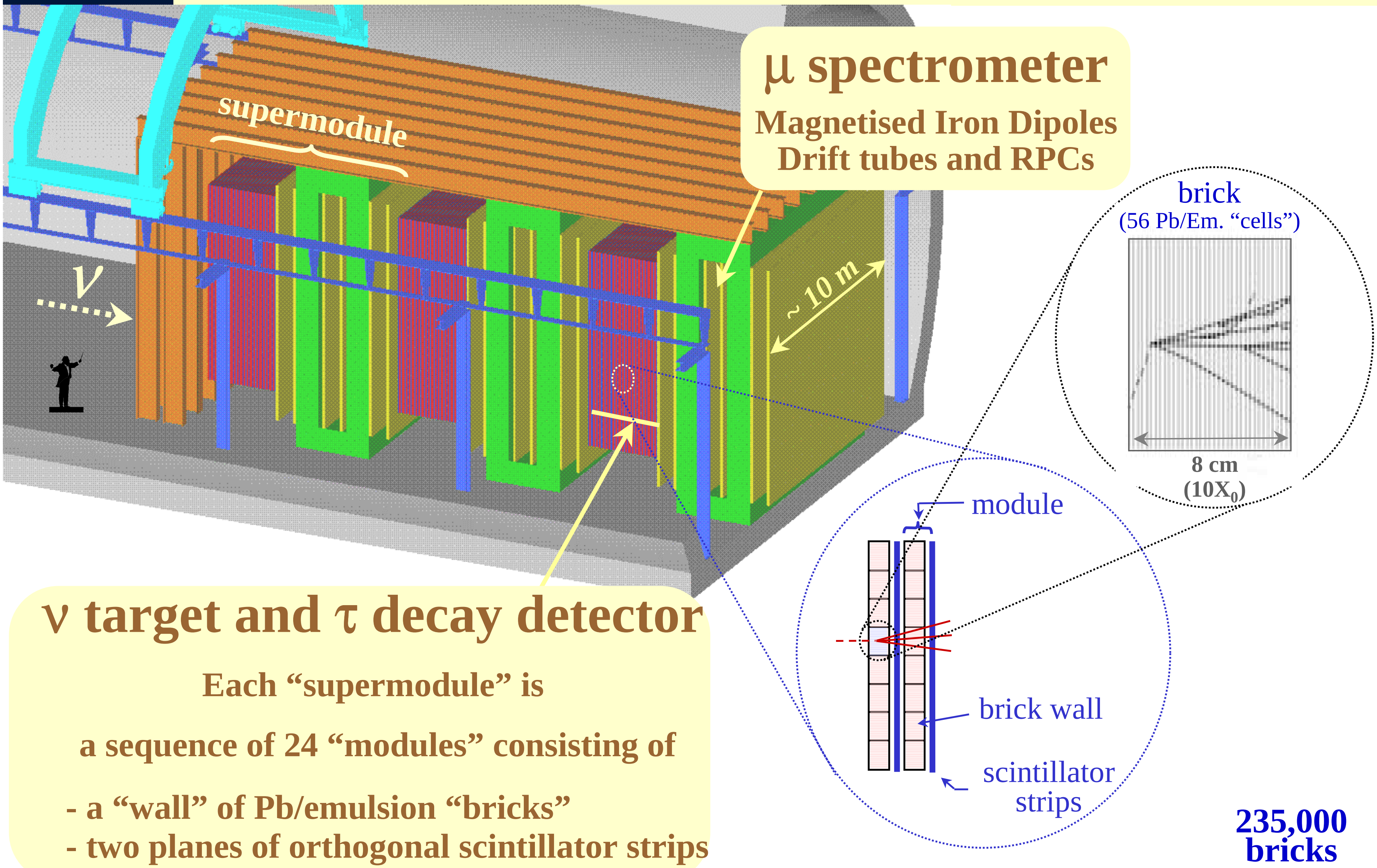
ν oscillation → massive target **<u>AND</u>** **τ decay → micron resolution**

Lead – nuclear emulsion sandwich

“Emulsion Cloud Chamber”

The detector at Gran Sasso

(modular structure, three “supermodules”)



μ spectrometer

Magnetised Iron Dipoles
Drift tubes and RPCs

ν target and τ decay detector

Each “supermodule” is

a sequence of 24 “modules” consisting of

- **a “wall” of Pb/emulsion “bricks”**
- **two planes of orthogonal scintillator strips**

Status of the experiment

Since the Proposal

- Full scale prototypes to finalise the detector design
- Progress in automatic scanning
- Studies of detection efficiency and backgrounds
- Sensitivity estimates updated with Super-K results
- Organisation structure for detector construction

Now: a "phase transition"

from studies and tests to construction

with related major investments of financial and human resources

Gran Sasso Detector

Preparation for production of emulsion films

- **Ten small batch productions and one large production of emulsion films by Fuji Co.**

- **"Emulsion Refreshing" tests**

  Satisfactory

- **Test of the complete cycle from emulsion production to readout**

(refresh – transport – brick assembly – beam exposure –development - read-out)

  Currently being analysed

Emulsion "refreshing"

At production

Latent micro-track images *(cosmic rays, ambient radioactivity)*

→ ***interference with e-shower measurements***

Emulsion refreshing

Tested at Nagoya

A few days at ~30 ^{0}C and ~ 95% humidity

→ ***reduction of recognised micro-tracks by a factor ~100***

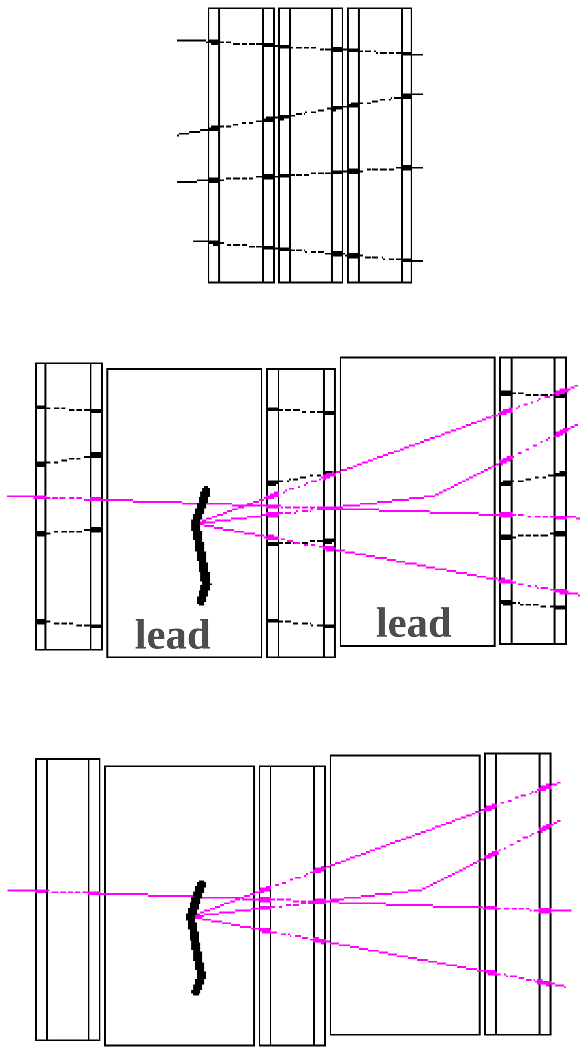
In the Proposal: refreshing at Gran Sasso

Limited underground space in relation to the large number of emulsion films (~14 million)

Now being considered:

- ***Refreshing in a Japan mine*** *(~ 100 m water equivalent depth)*
- ***Transportation of packed bricks*** *(without lead)*
- ***In the analysis: "virtual erasing" of micro-tracks*** *recorded during transportation*

"Virtual erasing" of background tracks
recorded during transportation



Transportation
Emulsions packed (without lead)

↓

Exposure
Micro-tracks recorded during transportation appear as staggered

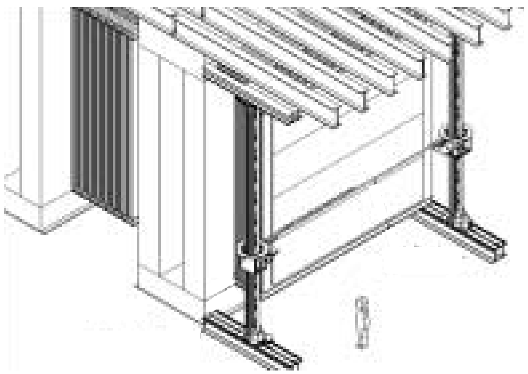
↓

Analysis
"virtual erasing"
of micro-tracks connected
in the configuration without lead

Established technique in CHORUS
(for periods with different emulsion alignment)

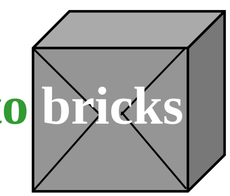
Brick production and handling

Fill the brick walls (BMS)
235,000 bricks



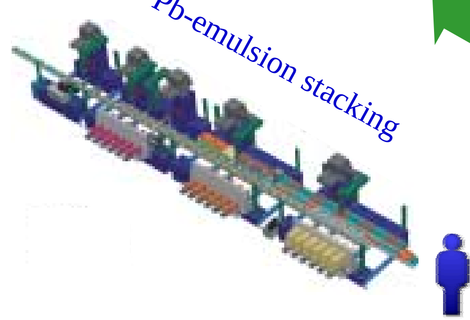
Extract bricks
after ν interactions
~ 40 bricks/day

Packing into bricks
(BAM)



brick packing

Pb-emulsion stacking



Components
Emulsion - 36 ton
Lead – 2 kton
“Origami” paper - 20,000 m^2

The Brick Assembly Machine (BAM)

27 million lead plates + emulsion sheets

A "factory" with high quality requirements

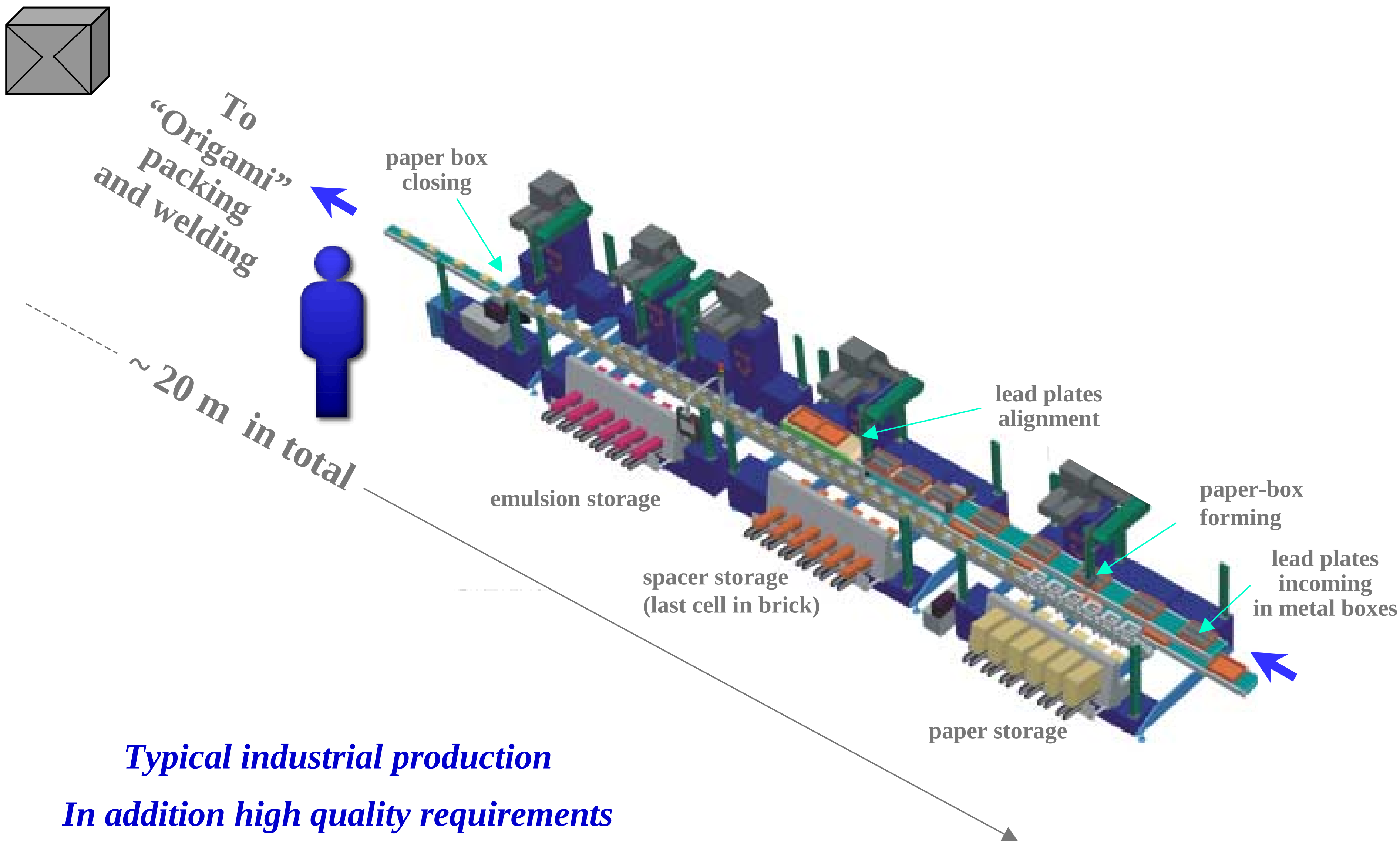
1) *Stack lead plates and emulsion sheets*
2) *"Origami" vacuum packing and welding*
3) *Vacuum quality control*

235,000 bricks at a rate of ~ 2 bricks/minute

Specifications formulated
Contacts with several industries ongoing
Market survey launched by CERN
Prototype packing system in October at Nagoya

The Stacking Section of the BAM

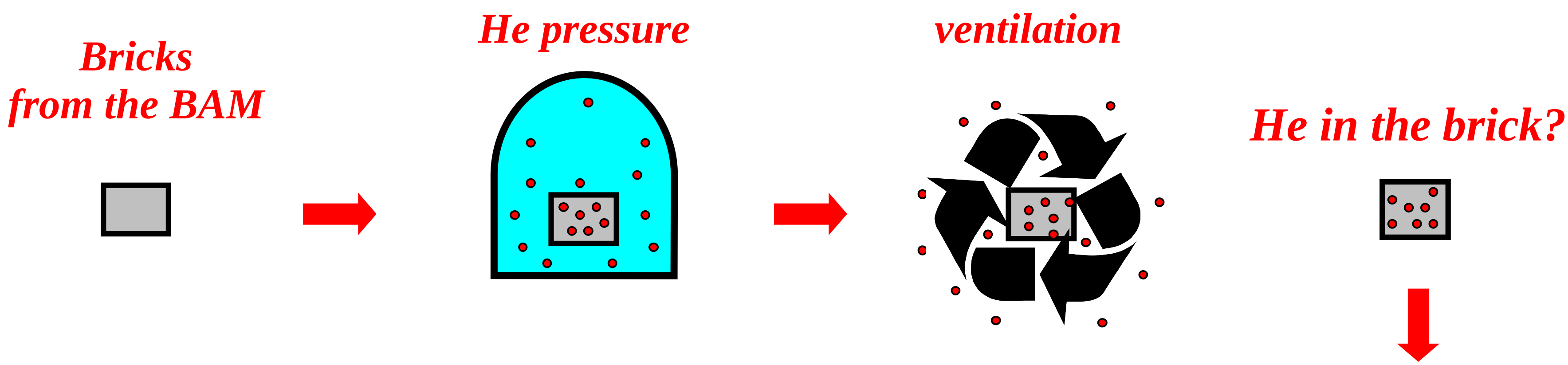
(as proposed by a firm)

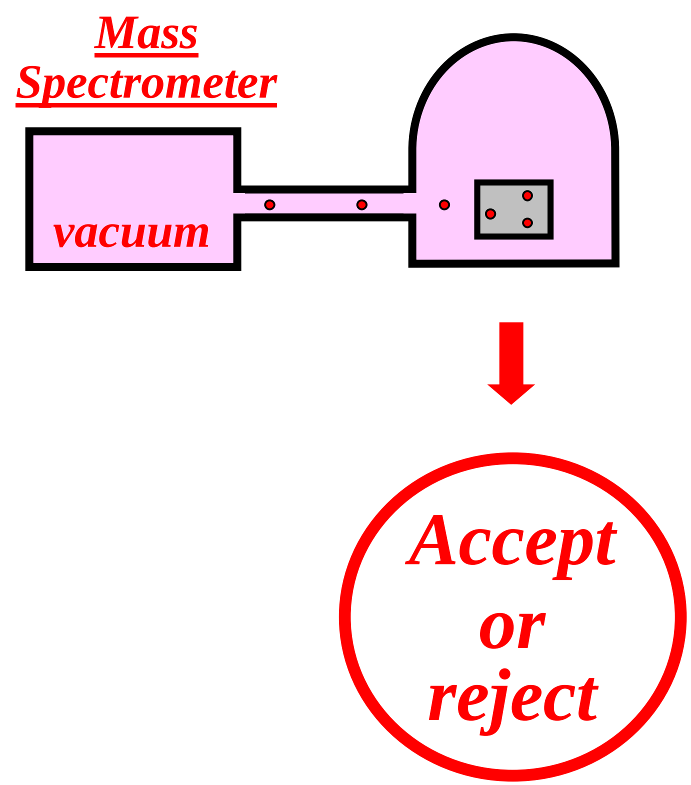


Typical industrial production

In addition high quality requirements

Schematics of brick vacuum control



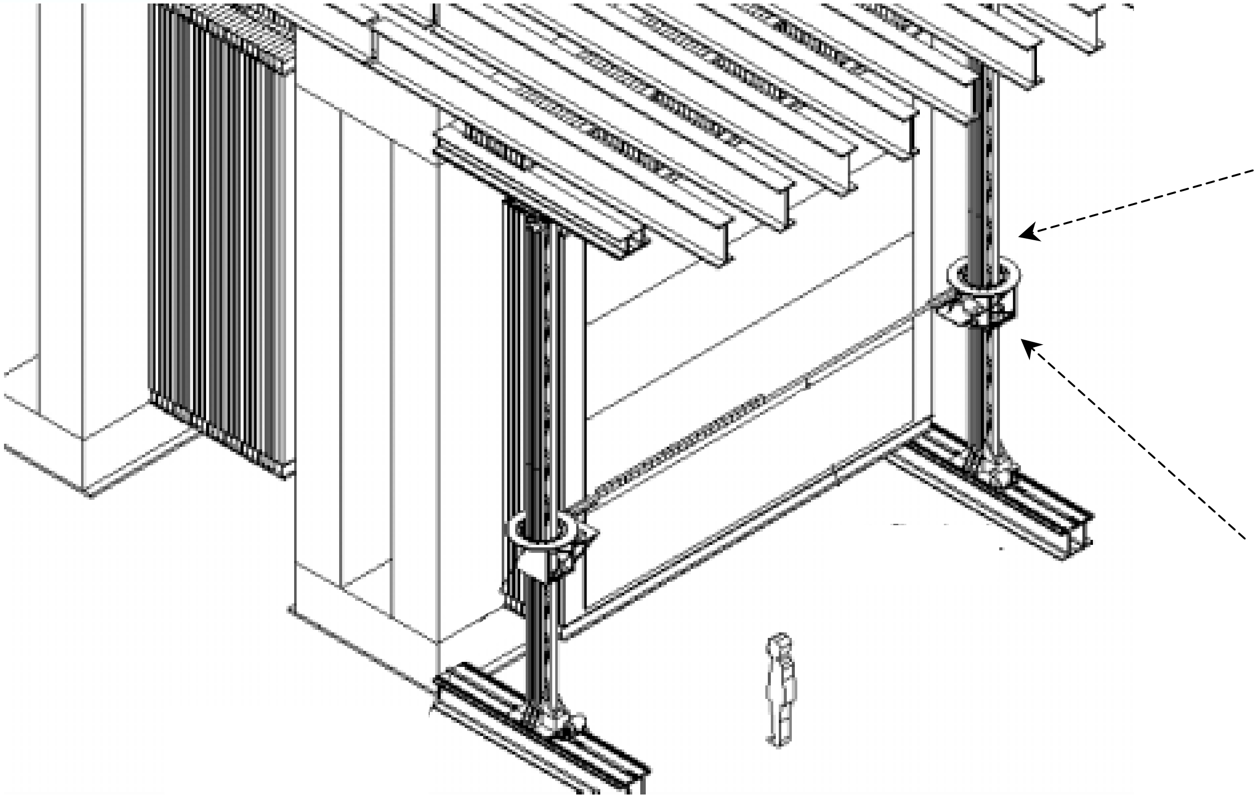


Vacuum must be maintained for several years !

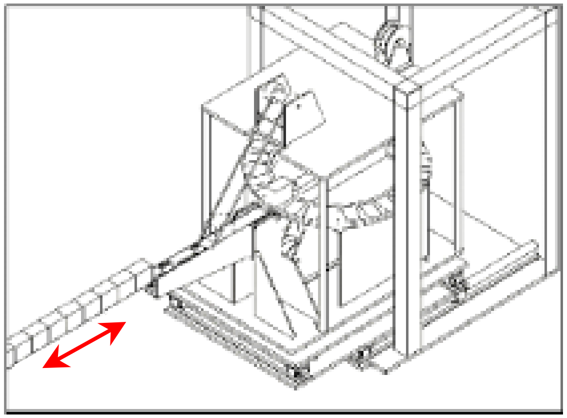
Vacuum quality control is an important additional step in brick assembly

Collaboration with industry
He-penetration tests in progress
Specifications in November

The Brick Manipulator System (BMS)



“Carousel” brick dispenser and retriever

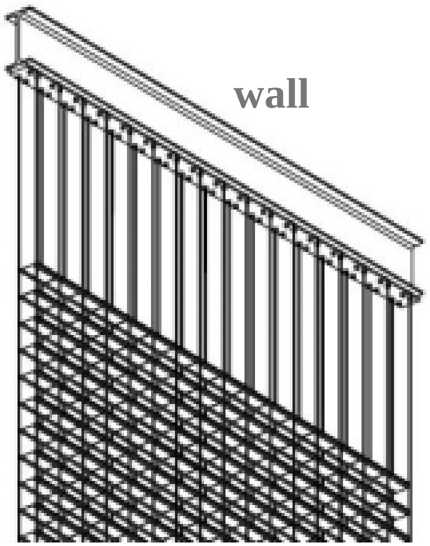


Carousel model at LAPP

Design
Carousel model
Brick sliding tests ➡ “skates”
Brick insertion and retrieval tests
Position sensors and automation
Full scale – reduced size model in construction
Collaboration with industry
Final project definition in November

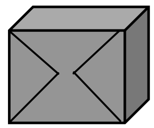
Support structure of the brick walls

Suspension from the top

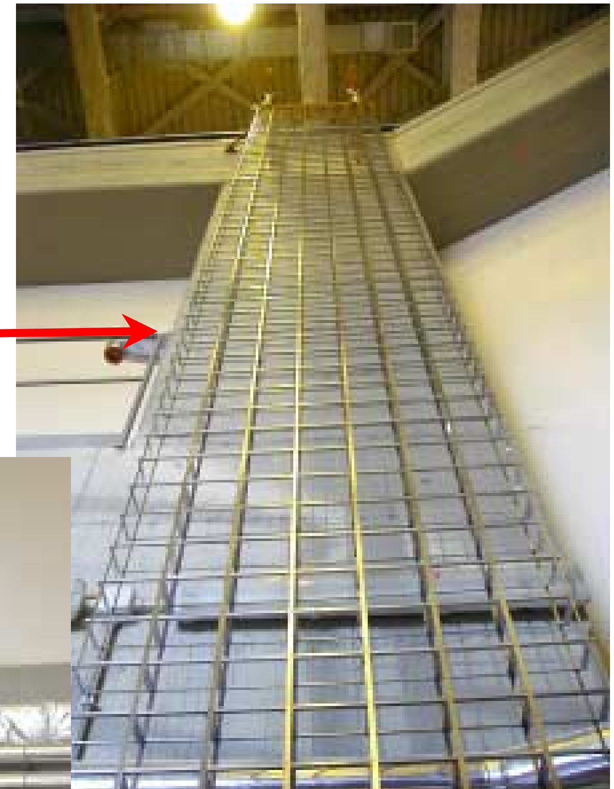


wall

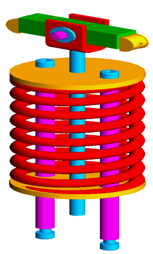
Brick loading test

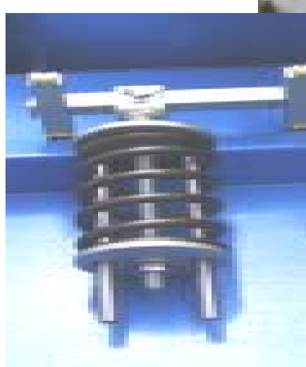


Bricks inserted from the side



Tensioning from the bottom





Tests of full scale wall prototypes and components
(Frascati and Naples)

Target Tracker: plastic scintillators

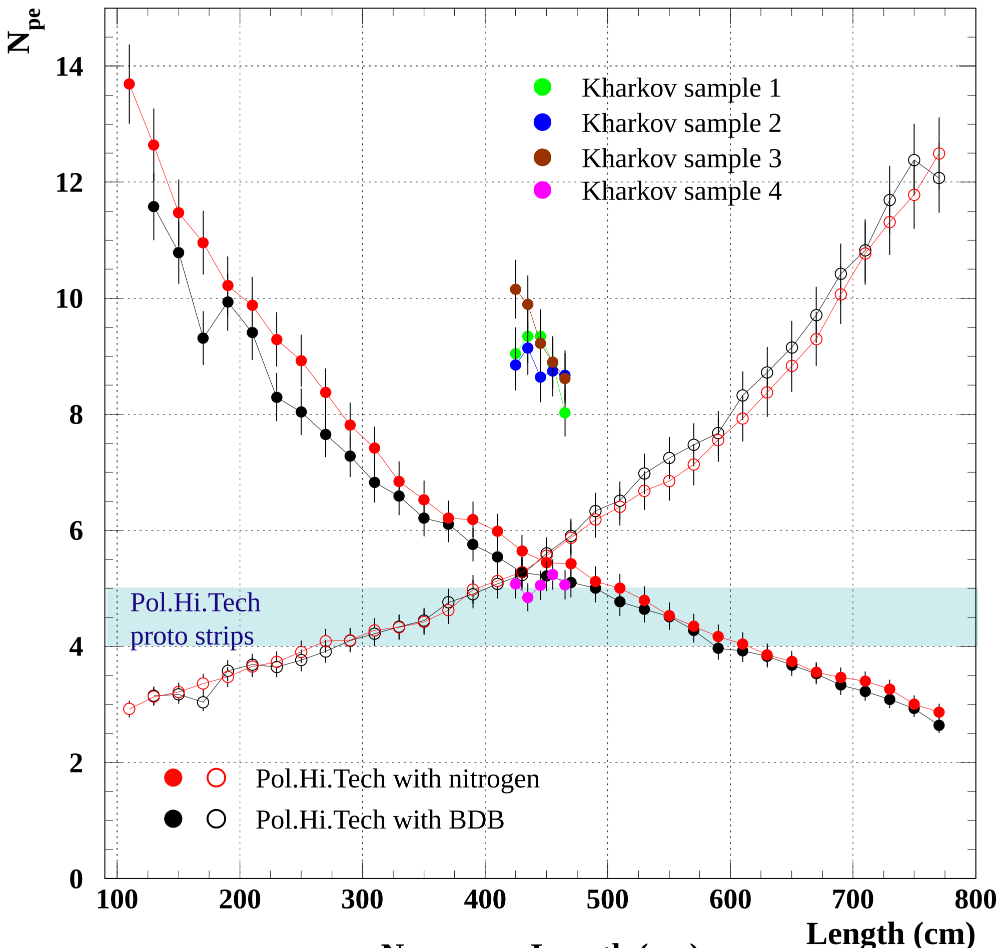
Full scale prototype module
(constructed at IReS Strasbourg)

- **64 strips of 6.7 m length, 2.6 cm width, 1 cm thickness**
- **readout by wavelength shifting optical fibres**

Milestones achieved

✓ "Full size 64-strip module prototype with industrially produced scintillator"	March 2001
✓ "Finalise design"	July 2001

Light output



N_{pe} versus Length (cm)

Pol.Hi.Tech

- full length extruded scintillator strips
- normal atmosphere replacing POPOP by BDB
- POPOP under inert atmosphere

Amcrys-H (Kharkov)

- extrusion tests of 2 m scintillator strips
- tests with full length fibres

> 5 p.e. / readout end

(in the middle, worst case for two-end readout)

Target Tracker construction

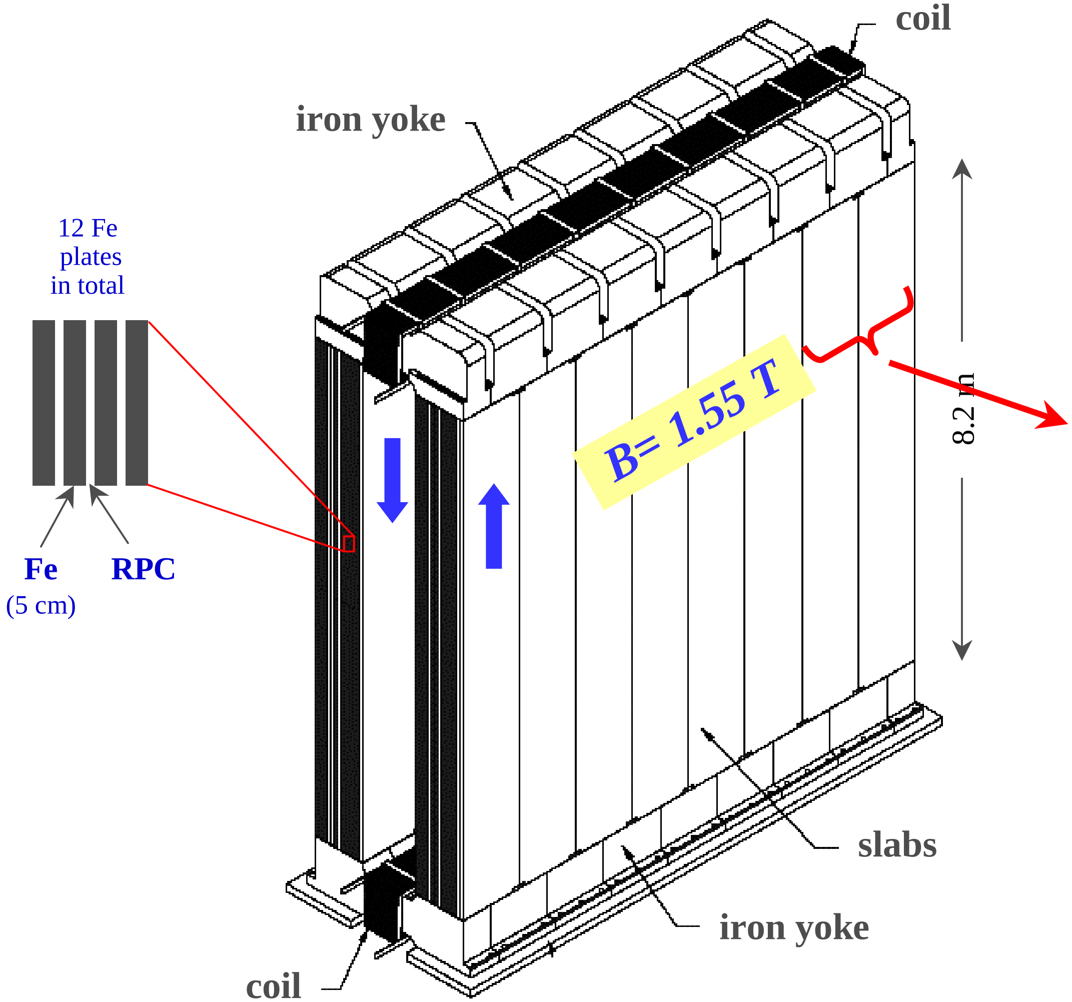
- **Baseline option: plastic scintillators**
  - **Milestones achieved**
  - **Contacts with industry for assembly of full modules**
- **Soon <u>final</u> decision**

Other options investigated: liquid scintillator and RPCs

- Extensive studies, tests, contacts with industry (see Status Report)
- Capability of mass production within schedule must be ensured

Dipolar spectrometer magnet

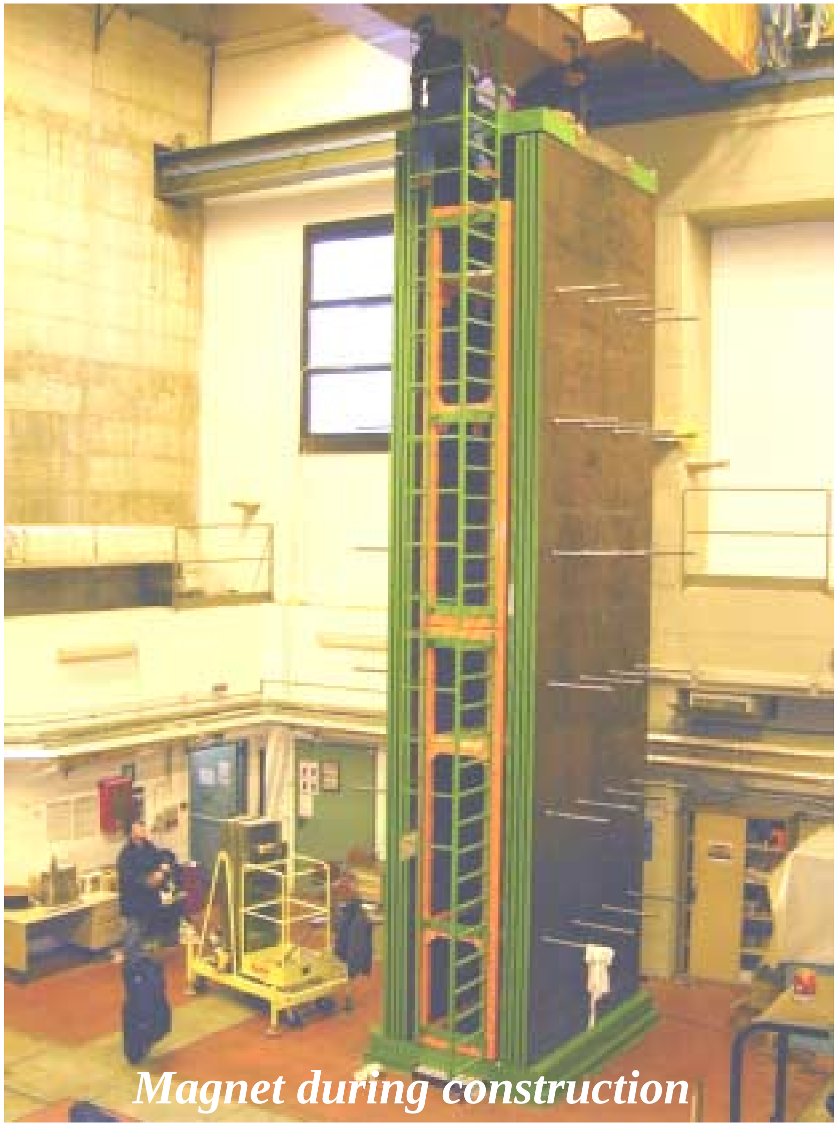
(RPCs inside gaps for muon identification)



Total weight ~ 1 kton

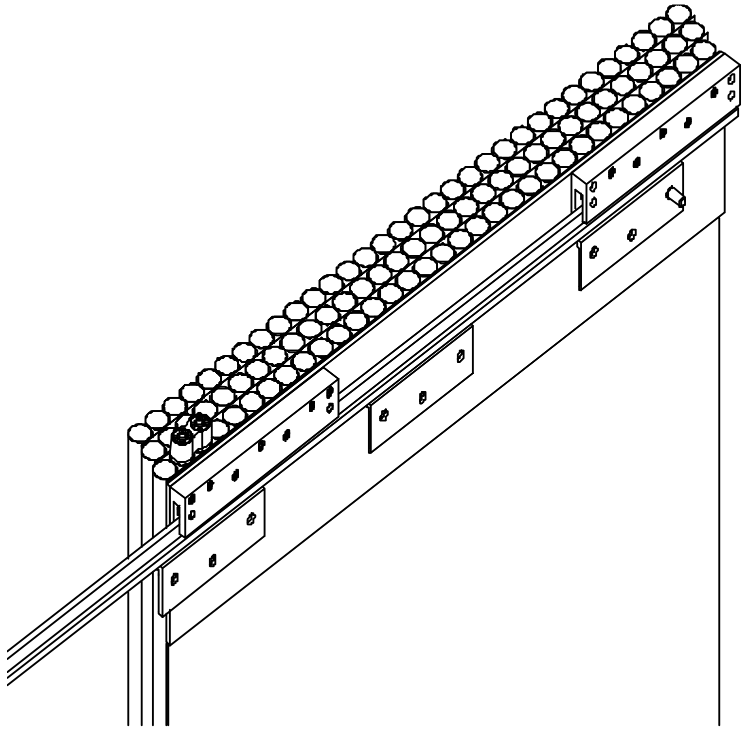
Iron in tendering-ordering phase

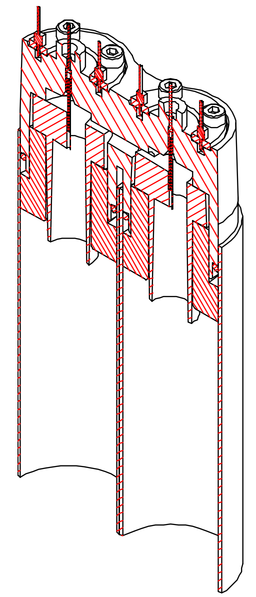
Full scale prototype of magnet section constructed and tested at Frascati



Drift tube spectrometer trackers

(muon momentum measurement)





Tests of <u>8.1 m</u> tubes

- *Wire stability*
- *Attenuation length*

Overall Assembly

- *Study of optimal staggering*
- *Mechanical design*
- *Negotiations for mass production*
- *Production of prototype (1 m) module started*

End Caps

- *Design and tests*
- *Negotiations for mass production*

Electronics

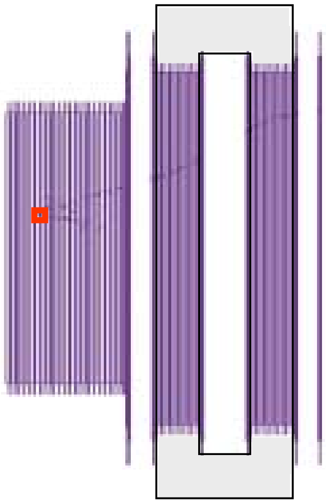
- *Design and tests*

Emulsion scanning

From the CNGS to physics: <u>where</u> work is done

ν

CNGS



brick extraction

~40/day

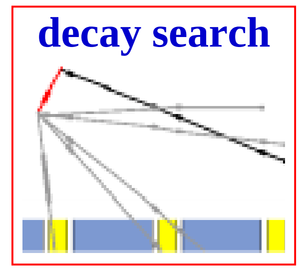
cosmic ray exposure

emulsion processing

Gran Sasso

no vertex : extract nearby bricks?

candidate : extract additional bricks?



Scanning Stations
(quasi-online)

candidate events

~4/day

FULL emulsion analysis

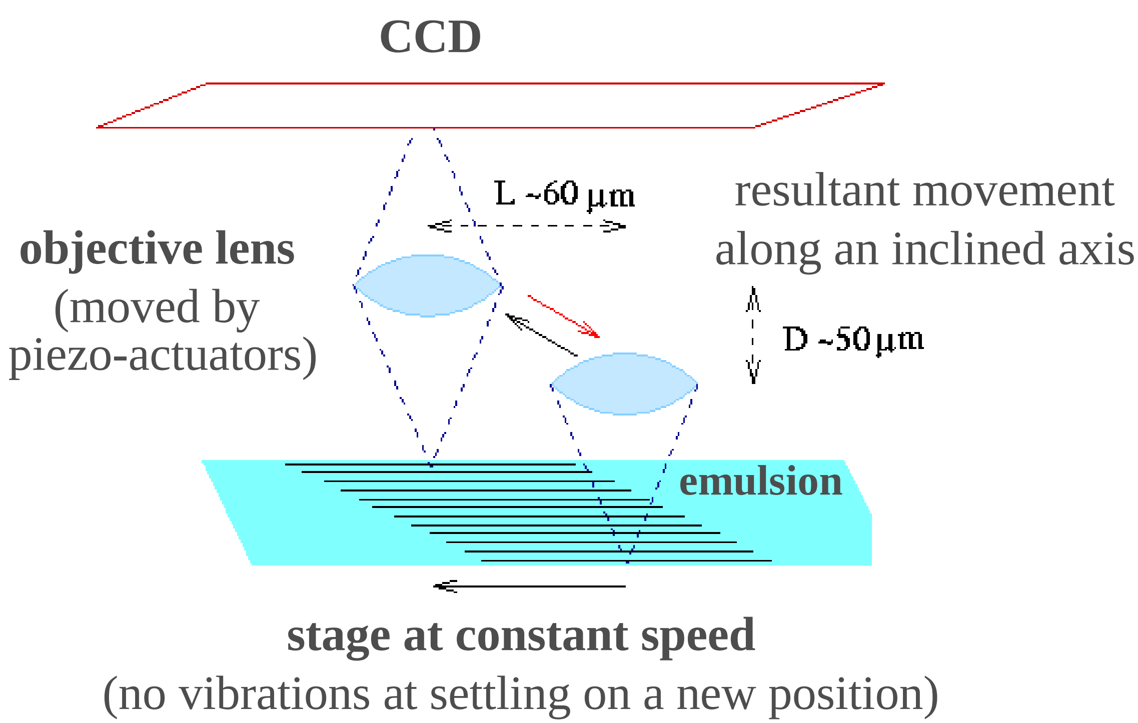
Scanning Labs

Physics

<u>All Labs</u>

The new concept for the S-UTS mechanics

(take images without stopping the stage)



Objective and stage movements synchronised

Emulsions are scanned vertically, in their reference frame

S-UTS development at Nagoya

Prototype of piezo-controlled objective lens
Achieved fluctuation of the stage movement < 0.5%

Synchronization tests completed

Real DAQ
using current CCD + UTS electronics
in September

Fast CCD + S-UTS electronics $\rightarrow$ 20 cm^2/hour
March 2002

Mechanics:
the critical R&D

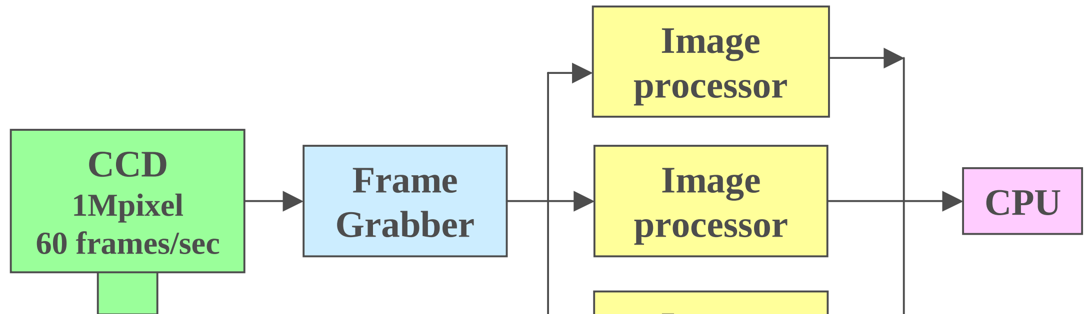
Tests with films

The Emulsion Scanning Facility in Nagoya University

Ready to allocate the new S-UTS fast scanning systems for OPERA

Development of automatic scanning in Europe

"Sysal" system operating in Salerno
R&D by Italian and other European laboratories



Design philosophy

Commercial components
(in continuous development)

Software approach

⬇

With present technology
10 cm^2/hour already feasible

Aim*
20 cm^2/hour

*** e.g. by new CC or CMOS sensors**

New automated microscope (Naples)

Large field of view
(350 x 350 μm^2)

No oil-immersion objectives

New small and fast stages
(change of view in ~80 ms)

1 Mpixel CCD camera
(60 frames/sec)

Parallel image processing

Plan for a Scanning Station in Europe

- **The Scanning Station takes the heaviest scanning load:**
  - **vertex location**

- **A Scanning Station planned in Italy as an European facility:**
  - 15 bricks/day with 24 hours/day scanning (~40 extracted daily)
  - about 13 automatic microscopes (scanning speed 20 cm^2/hour)
  - Physicists and operating crew working on shifts
  - Technical support, hardware/software experts
  - About 200 m^2 laboratory space

- **Emulsions sent to Collaboration laboratories for:**
  - **selection of events with decay topology**
  - **precision measurements on candidate events**

Sharing of responsibilities

(see Status Report)

TARGET	
Bricks	
emulsion films	Nagoya
film refreshing	Nagoya, Salerno
lead plates	CERN, INR, Münster
brick packing paper	INFN
brick holders	Annecy for R&D
spacers (downstream cells)	Nagoya for R&D
brick assembly machine	CERN; Nagoya and Naples for R&D
brick assembly	Collaboration
wall support structure	Frascati, Naples
brick handling machine	Annecy
brick installation	Collaboration
Emulsion facilities	
cosmic-ray alignment	Rome; Bologna, Nagoya and Kobe for R&D
film development	Salerno, Nagoya for R&D, Bari and Rome for infrastructure
emulsion packing	Nagoya for R&D
additional contributors to bricks and emulsion facilities	Aichi, Ankara, Beijing, Bologna, Israel, Kobe, Toho, Tsinan, Utsunomiya
Trackers (baseline option)	
scintillator modules	Bern, Brussels, CERN, Lyon, Strasbourg
photo-detectors	Bern, Brussels, Lyon, Strasbourg
read-out electronics	Bern, Brussels, Lyon, Orsay
plane assembly	Bern, Brussels, CERN, Lyon, Strasbourg
calibration system	Bern, Brussels, CERN, Lyon, Strasbourg
responsibilities to be defined	Israel, ITEP, JINR Dubna, Neuchatel, Zagreb
MUON TAGGING AND MOMENTUM MEASUREMENT	
Magnets	
yokes	Frascati
coils	Frascati
power supplies	to be defined
Inner detectors and XPCs	
RPCs and XPCs, strips, power supplies	CERN, Frascati, INR, LNGS, Padova, Zagreb
gas system	Frascati, Padova
read-out electronics	CERN, Frascati, Padova
Precision trackers	
drift tubes, gas, power supplies	Hamburg, ITEP
read-out electronics	Hagen, Münster, Rostock
Veto system and beam monitoring	INR, LNGS, Zagreb
Overall support structure	Frascati, Naples
ALIGNMENT AND SURVEY	to be defined
DAQ AND SLOW CONTROL	Lyon, Strasbourg
EMULSION READ-OUT (ONLINE)	CERN, France, Germany, Italy, Japan, Switzerland

Sensitivity to oscillations

Latest results from Super-Kamiokande and K2K

(Lepton-Photon Conference 2001)

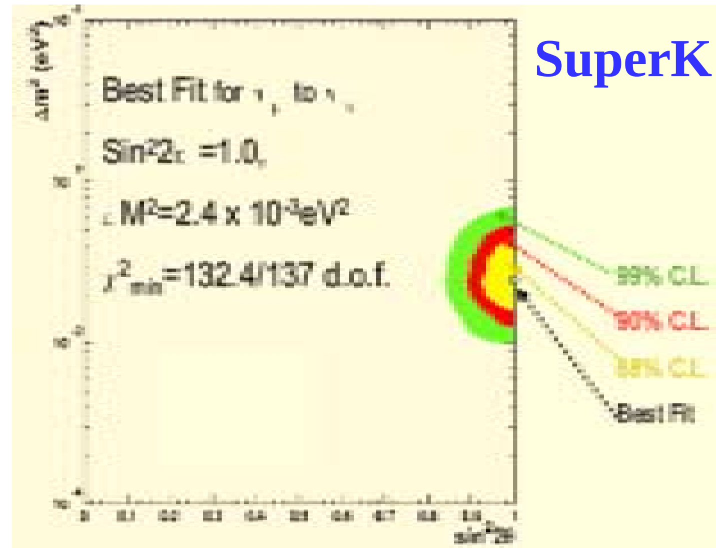
➤ ν_μ disappearance in Super-K

$\nu_\mu - \nu_\tau$

1.2 < Δm^2 < 5.4 x 10^{-3} eV^2 at 90% CL
1.0 7.0 99%

Best fit $\Delta m^2 = 2.4 \times 10^{-3}$ eV^2

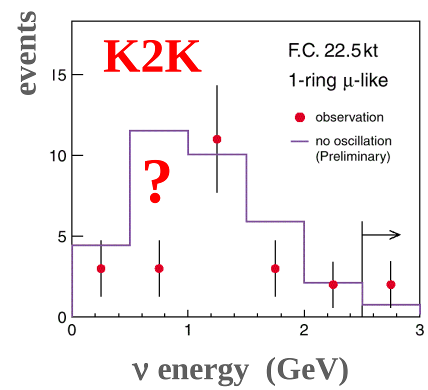
Sterile ν disfavoured at ~ 99%



➤ ν_μ disappearance in K2K

Expected (no osc.)	63.9 + 6.1 - 6.6
Detected	44 (~ 2σ effect)

Oscillation dip in the E_ν spectrum at $\Delta m^2 \sim 3 \times 10^{-3}$ eV^2 ?



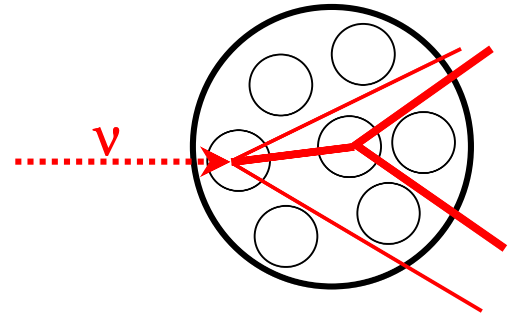
➤ ν_τ appearance in Super-K

Poor S/B ratio ~ 0.7%, statistical significance ~ 2σ

Improvements in the event simulation and reconstruction

➢ Event generator

- Tuned on NOMAD data
- Simulation of re-interactions within the lead nucleus
  $\rightarrow$ increased multiplicity of secondaries
  $\rightarrow$ softening of the momentum spectrum



➢ Tracking by the electronic detectors

Use of Kalman filter techniques

$\rightarrow$ improved angular resolution for the μ track: **40 $\rightarrow$ 20 mrad**

➢ Muon identification

Matching the muon track in the electronic detectors
to the reconstructed tracks in the emulsions

Neutrino interactions

Nominal ν beam (Nov. 2000)

Shared SPS operation

200 days/year

4.5×10^{19} pot / year

5 year run

1.8 kton average target mass

(accounting for mass reduction with time, due to brick removal for analysis)

Possible increase in SPS proton intensity for LHC not considered here

Expected interactions

~ 33000 ν_μ NC+CC

~ 120 ν_τ CC

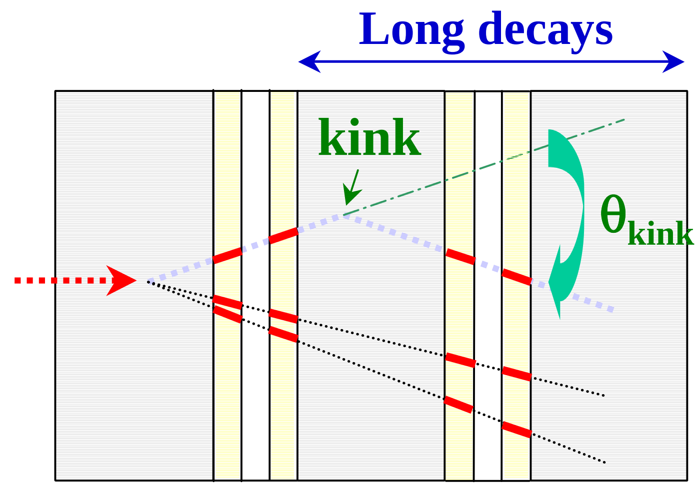
at $\Delta m^2 = 2.4 \times 10^{-3}\ eV^2$ and full mixing

Exploited τ decay channels

- **"Long" decays**

  kink angle θ_{kink} > 20 mrad

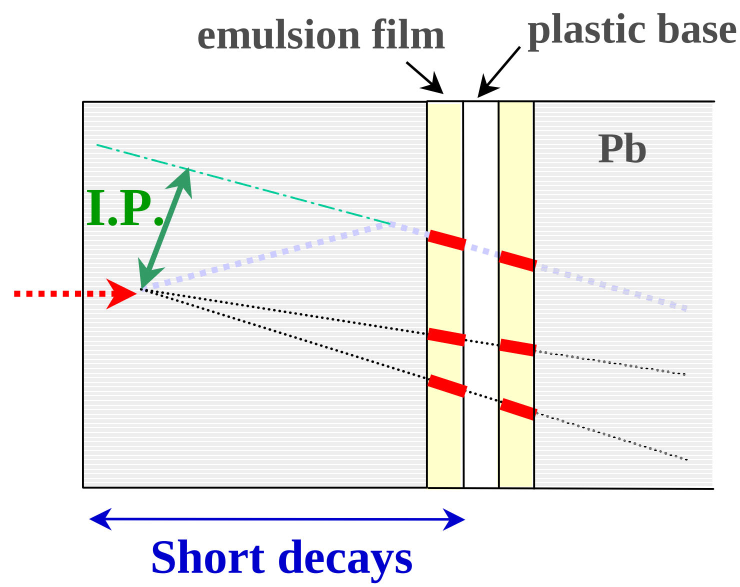
$\tau \rightarrow$ **e**	Progr. Rep.	1999
$\tau \rightarrow \mu$	Progr. Rep.	1999
$\tau \rightarrow$ **h ($n\pi^0$)**	Proposal	2000
+ ρ **search**		**2001**



- **"Short" decays**

  impact parameter I.P. > 5 to 20 μm

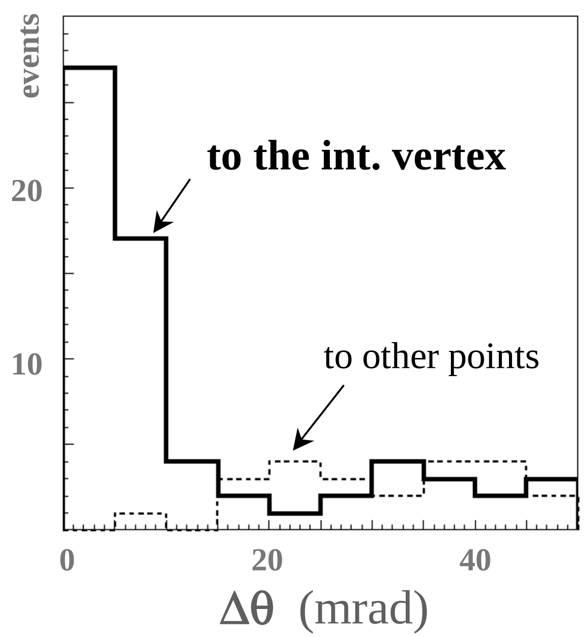
$\tau \rightarrow$ **e**	Proposal	2000
$\tau \rightarrow \mu$		**2001**



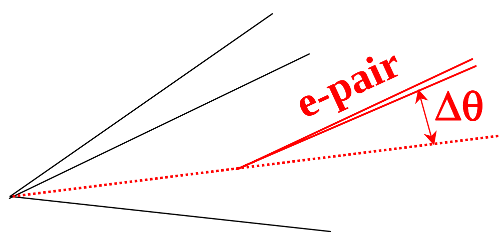
Pointing accuracy to the vertex of e-pairs from γ conversions

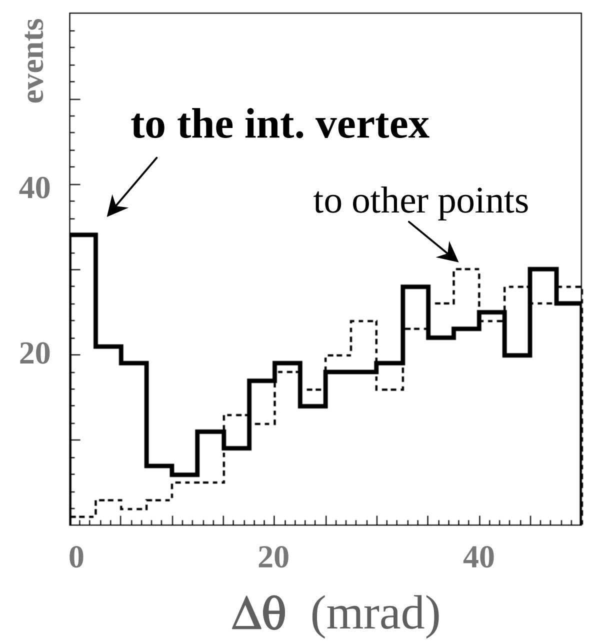
Studied in CHORUS and DONUT by NetScan

(½ X_0 depth in ECC)



CHORUS





DONUT

(ECC Fe-emulsion)

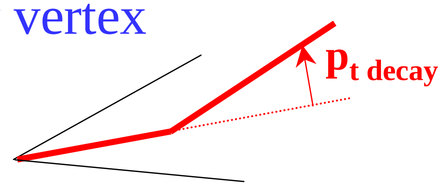
Important for increasing the sensitivity to $\tau \rightarrow h\, n\pi^0$

Hadronic long decays:

higher efficiency for $\tau \to \rho \to \pi^- \pi^0$ with vertex assignment to γs

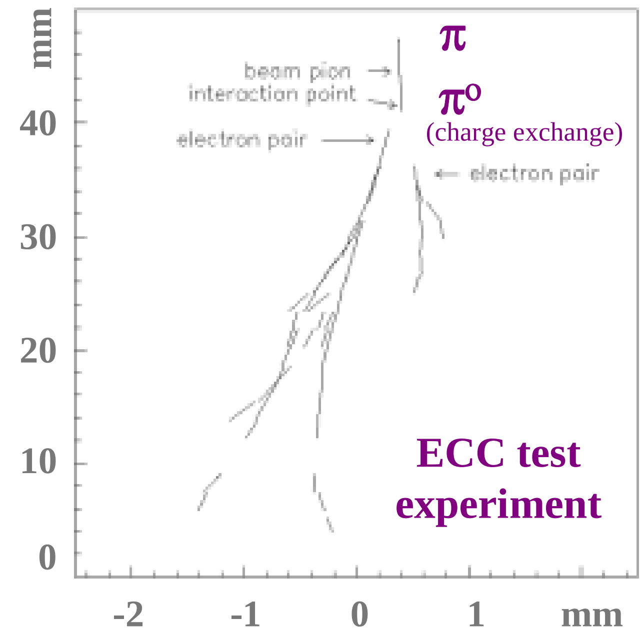
- B.R.= 25.4% (49.5% for full $\tau \to h$)

- **γs** assigned to primary or to decay vertex **depending on <u>Impact Parameter</u>**



- **<u>if a γ is assigned to the decay vertex</u>**
  $\to$ **improved $p_{t\ decay}$ resolution** (charged+neutral)
  $\to$ **<u>looser cut and higher efficiency</u>**

- Improved missing p_t resolution

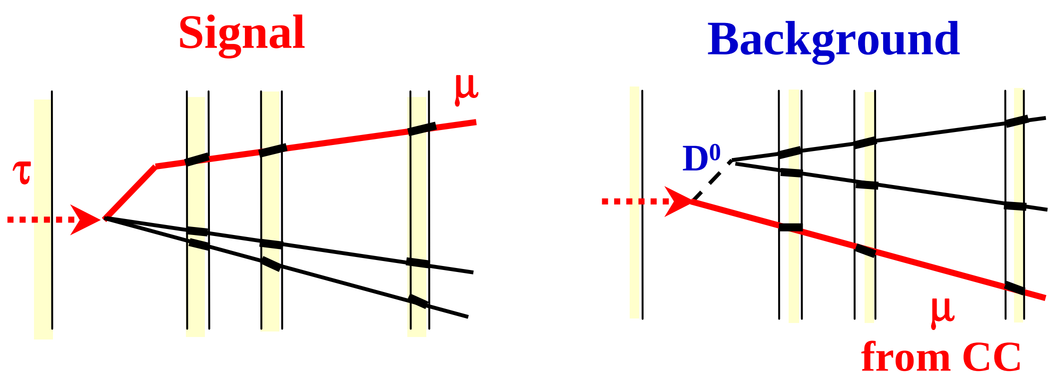


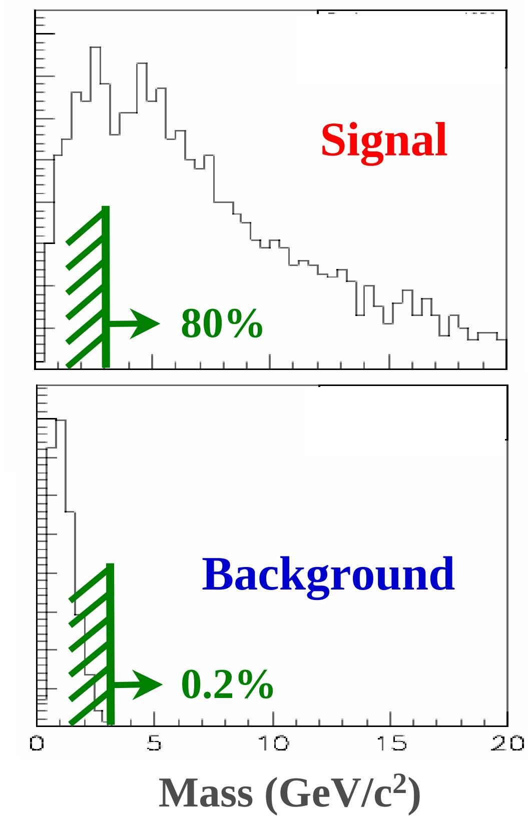
- Probability for a hadron interaction to give a γ pointing to a decay vertex O(1%)
  $\to$ no additional background

Efficiency for $\tau \to h$ long decays: 2.3 $\to$ 2.9 %

(including a 10% reduction in the brick finding efficiency and
a 20% reduction due the inclusion of nuclear reinteractions in the event generator)

Muonic short decays by Impact Parameter





➢ Main background

- charmed particle decay vertex mistaken as primary vertex
- μ from ν_μ CC faking $\tau \to \mu$ because of its large IP

➢ Event selection

- Reconstruct the invariant mass M of the particles assigned to the vertex defined as primary ($\geq$ 2 tracks)
- With 50% mass resolution and M > 3 GeV/c^2 cut only 0.2% of the charm background survives

Contribution to τ detection efficiency x BR : 0.7 %

Summary of τ detection efficiencies

(in % and including BR)

	DIS long	QE long	DIS short	Overall*
$\tau \to e$	$\boxed{2.7}$	$\boxed{2.3}$	1.3	3.4
$\tau \to \mu$	$\boxed{2.4}$	$\boxed{2.5}$	0.7	2.8
$\tau \to h$	2.8	3.5	-	2.9
Total	8.0	8.3	1.3	9.1 (8.7)

* weighted sum of DIS and QE events

Efficiency given in the Proposal

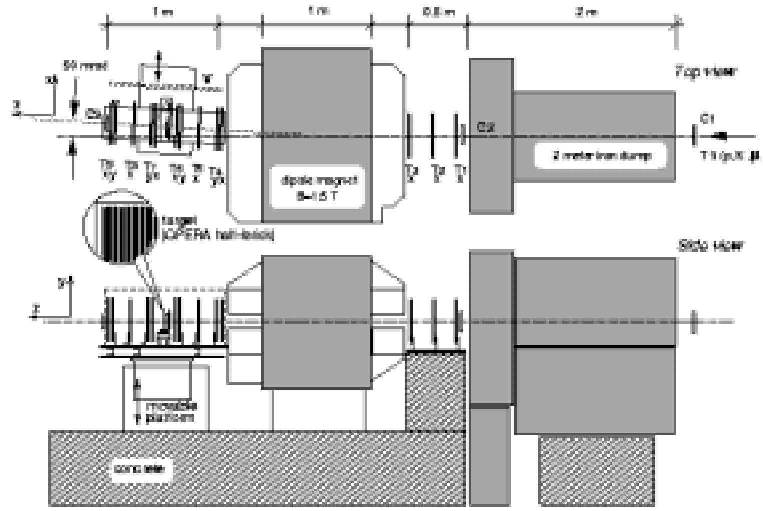
Channels considered at the time of the CNGS approval in 1999 :

$\tau \to e$ (DIS+QE, long)	3.0
$\tau \to \mu$ (DIS+QE, long)	2.6

Overall efficiency $\varepsilon = \underline{5.6}$

Progress in understanding backgrounds

Large angle μ scattering: dedicated experiment at the CERN-PS



- Pure μ beam (2 m Fe dump)
- $\sigma(\theta) \sim$ 2mrad, $\sigma(p) \sim 0.06{*}p$

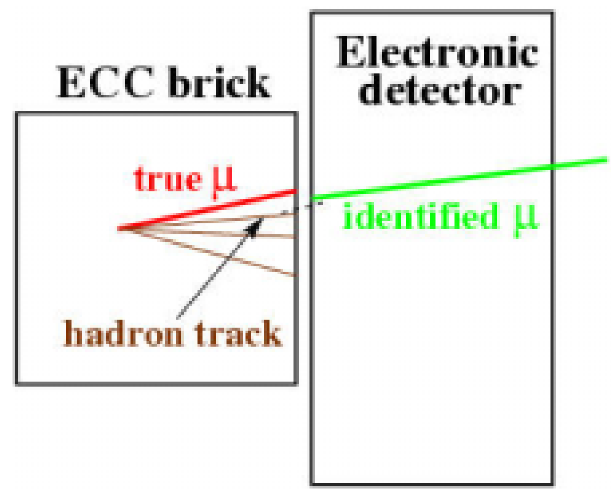
  $\rightarrow$ preliminary result $\mathbf{0.6^{+0.7}_{-0.6}}$ **x** $\mathbf{10^{-5}}$ $\mathbf{N_\mu}$
  consistent with Proposal's estimate (1.0×10^{-5})

Backgrounds to $\tau \rightarrow \mu$ long decays from re-interacting hadrons

(anticipated but not yet estimated in the Proposal)

- ν_μ **NC** interactions with a hadron misidentified as a muon
  (6% probability) and matched to a track in emulsions
  $\rightarrow$ **4.4 x** $\mathbf{10^{-6}}$ **x** $N\nu_\mu$ $_{\text{CC DIS}}$ **events**

- ν_μ**CC** interactions with an identified μ mismatched
  (2% probability) to a hadron in the emulsions
  $\rightarrow$ **2.6 x** $\mathbf{10^{-6}}$ x $N\nu_\mu$ $_{\text{CC DIS}}$ **events**



Expected background

(5 year run with 1.8 kton average target mass)

		$\tau \rightarrow e$	$\tau \rightarrow \mu$	$\tau \rightarrow h$	*Total*
LONG DECAYS	*Charm production*	0.14	0.03	0.14	0.31
	ν_e *CC and* π^0	0.01	-	-	0.01
	Large angle μ *scattering*		0.10	-	0.10
	Hadron reinteractions	-	-	0.10	0.10
	ν_μ CC		$\boxed{0.06}$		0.06
	ν_μ NC		$\boxed{0.10}$		0.10
	Total	0.15	0.29	0.24	0.67
SHORT DECAYS	*Charm production*	0.03	0.02	-	0.05
	Large angle μ *scattering*	-	0.02	-	0.02
	ν_e *CC and* π^0	« 0.01	-	-	« 0.01
	Total	0.03	0.04	-	0.07
	Total	**0.18**	**0.33**	**0.24**	**0.75**

New estimates

⬆

0.57 in the Proposal

Expected number of events

(5 year run with 1.8 kton average target mass)

Full mixing, Super-Kamiokande best fit and 90% CL limits as presented at the 2001 Lepton Photon Conference

(update with respect to the EPS 2001 results taken for the written Status Report)

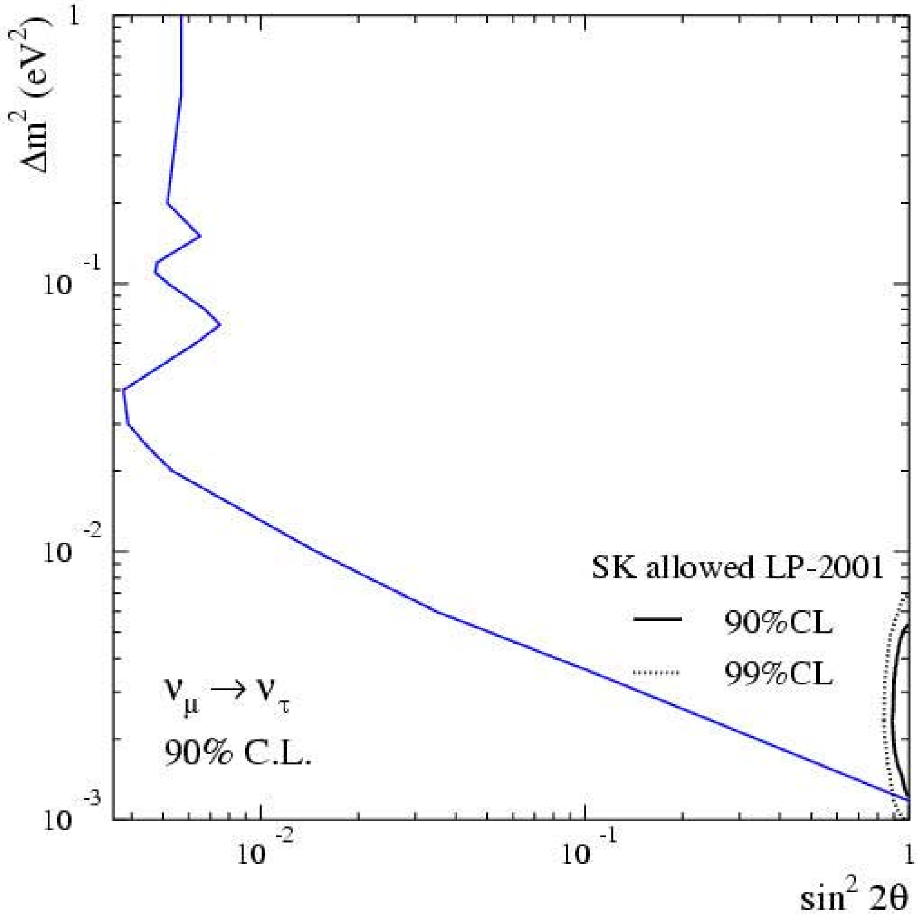
Decay mode	*Signal 1.2*10–3*	*Signal 2.4*10-3*	*Signal 5.4*10-3*	*Bkgnd.*
$\tau \to e$ long	0.8	3.1	15.4	0.15
$\tau \to \mu$ long	0.7	2.9	14.5	0.29
$\tau \to h$ long	0.9	3.4	16.8	0.24
$\tau \to e$ short	0.2	0.9	4.5	0.03
$\tau \to \mu$ short	0.1	0.5	2.3	0.04
Total	**2.7**	**10.8**	**53.5**	**0.75**

In the Proposal:

Δm^2	**1.5** x 10^{-3}	**3.2** x 10^{-3}	**5.0** x 10^{-3}	
events	**4.1**	**18.3**	**44.1**	**0.57**

Exclusion plot in the absence of a signal

(5 year run with 1.8 kton average target mass)



90 % CL upper limit obtained on average by a large ensemble of experiments

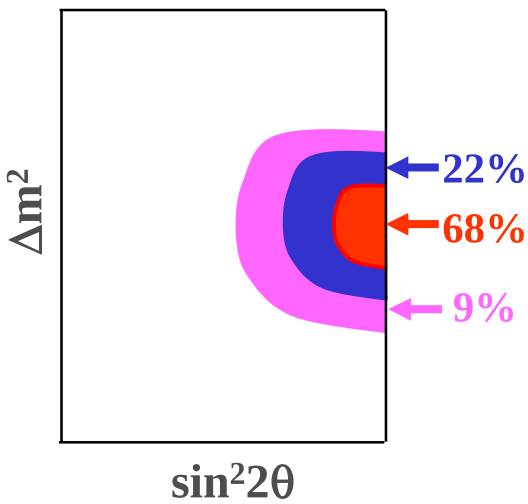
Δm^2	**$< 1.2\times10^{-3}$ eV^2 at full mixing**
$\sin^2(2\theta)$	**$< 5.7\times10^{-3}$ at large Δm^2**

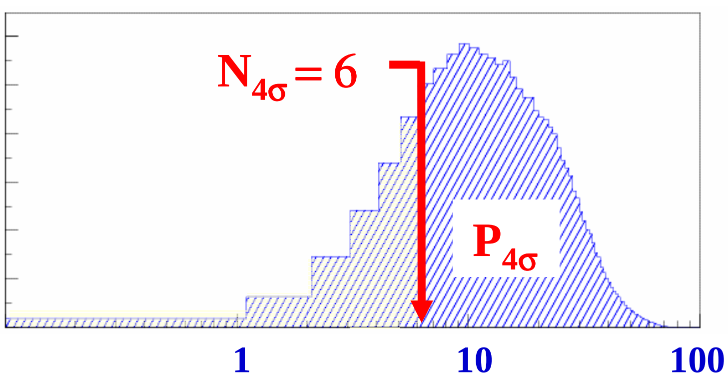
Gives an indication of the sensitivity … but of course we expect to see a signal

Uncertainties on background (±33%) and on efficiencies (±15%) accounted for here and in the following

Probability of $\geq n\sigma$ significance

Schematic view of the Super-K allowed region





Distribution of events observed

- **Simulate a large number of experiments** with oscillation parameters generated according to the Super-K probability distribution
- **$N_{4\sigma}$ events are required for a discovery at 4σ**
- **Evaluate the fraction $P_{4\sigma}$ of experiments observing $\geq N_{4\sigma}$ events**

Run	$P_{3\sigma}$ (%)	$P_{4\sigma}$ (%)
3 y	88	82
5 y	96	90

Probability of ≥ nσ significance for different Δm^2

(5 year run with 1.8 kton average target mass)

$\Delta m^2 (eV^2)$	$P_{3\sigma}$	$P_{4\sigma}$
1.6*10-3	78%	44%
1.8*10-3	89%	64%
2.0*10-3	95%	79%
2.2*10-3	98%	91%
2.4*10-3	99%	95%

Super-Kamiokande (LP 2001)

$1.2 < \Delta m^2 < 5.4 \times 10^{-3}$ eV^2 at 90% CL

1.0 7.0 99%

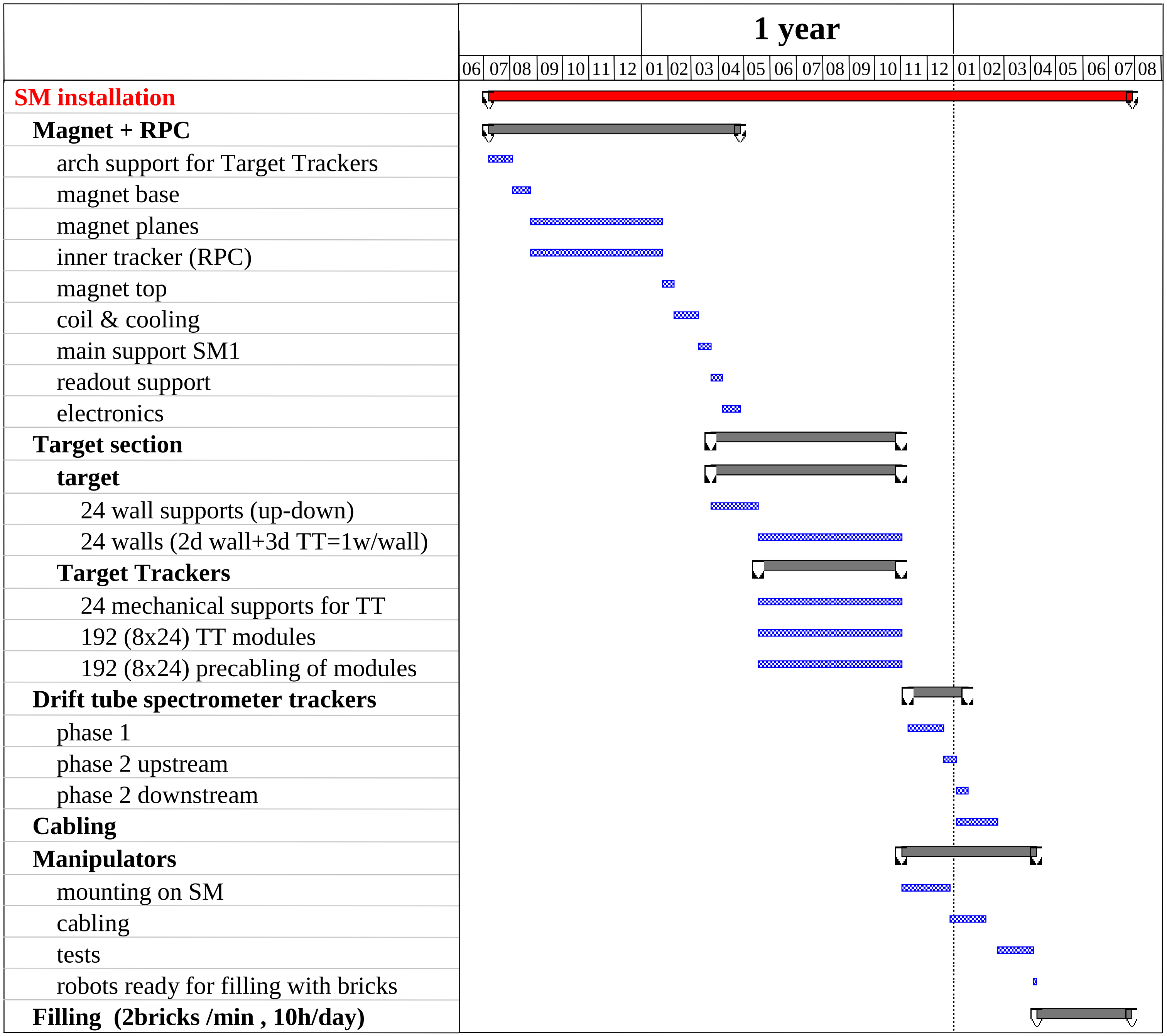
Best fit $\Delta m^2 = 2.4 \times 10^{-3}$ eV^2

Installation and schedule

Installation in a restricted space

“Simple” problems can be solved with time and patience! ….

… but others are
by far more complex and
do not have time as a free parameter



Schedule for the installation of <u>one</u> <u>supermodule</u>

⬇

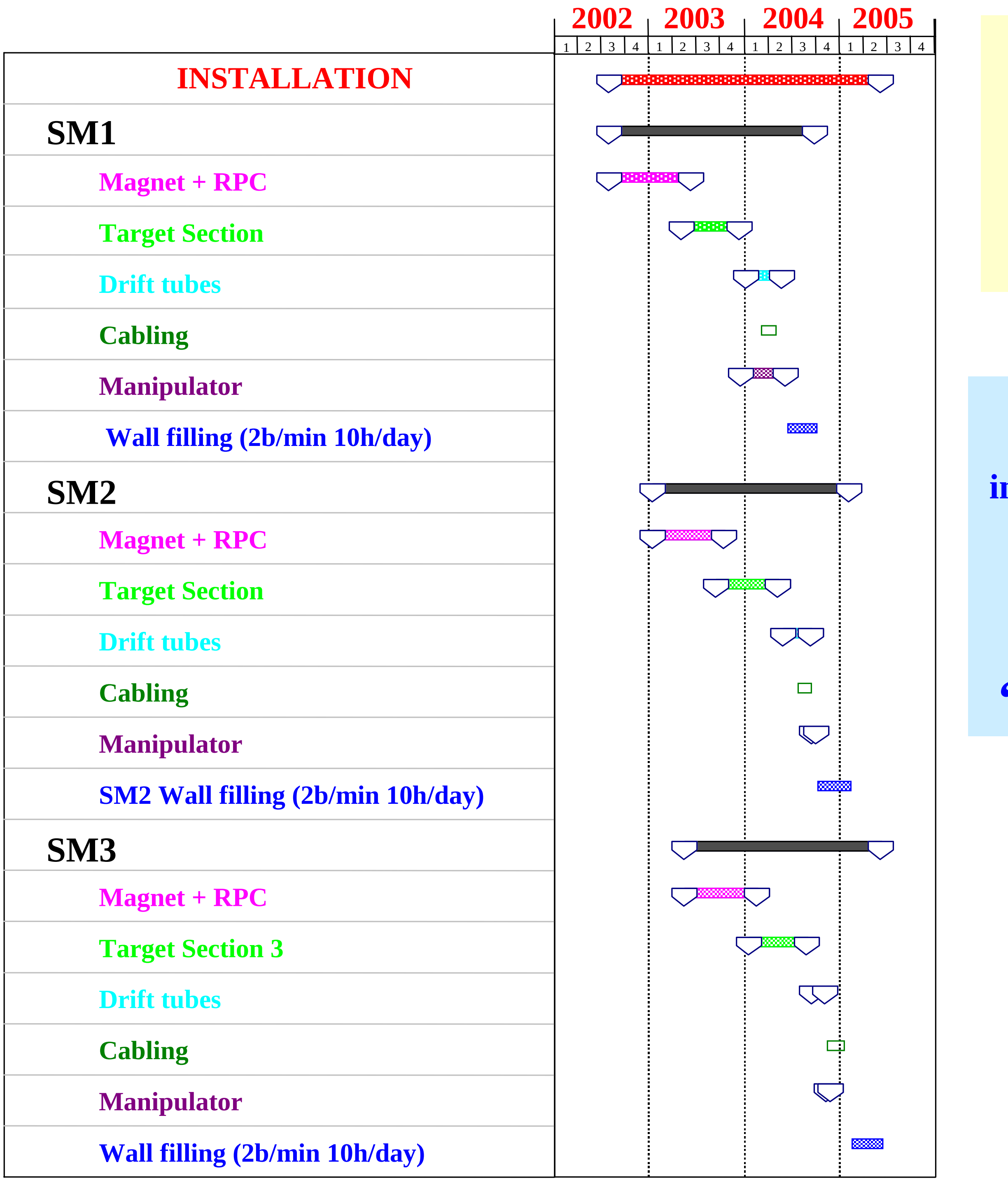
<u>two years</u> needed

To have the full detector at the beam start-up in 2005

One supermodule in 2 years
Three supermodules in 3 years

The three supermodules
"must"
be installed largely in parallel

(in the limited space available underground)



Schedule
to have the full detector ready in 2005

Large parallelism
in the mounting of the supermodules

Limited space

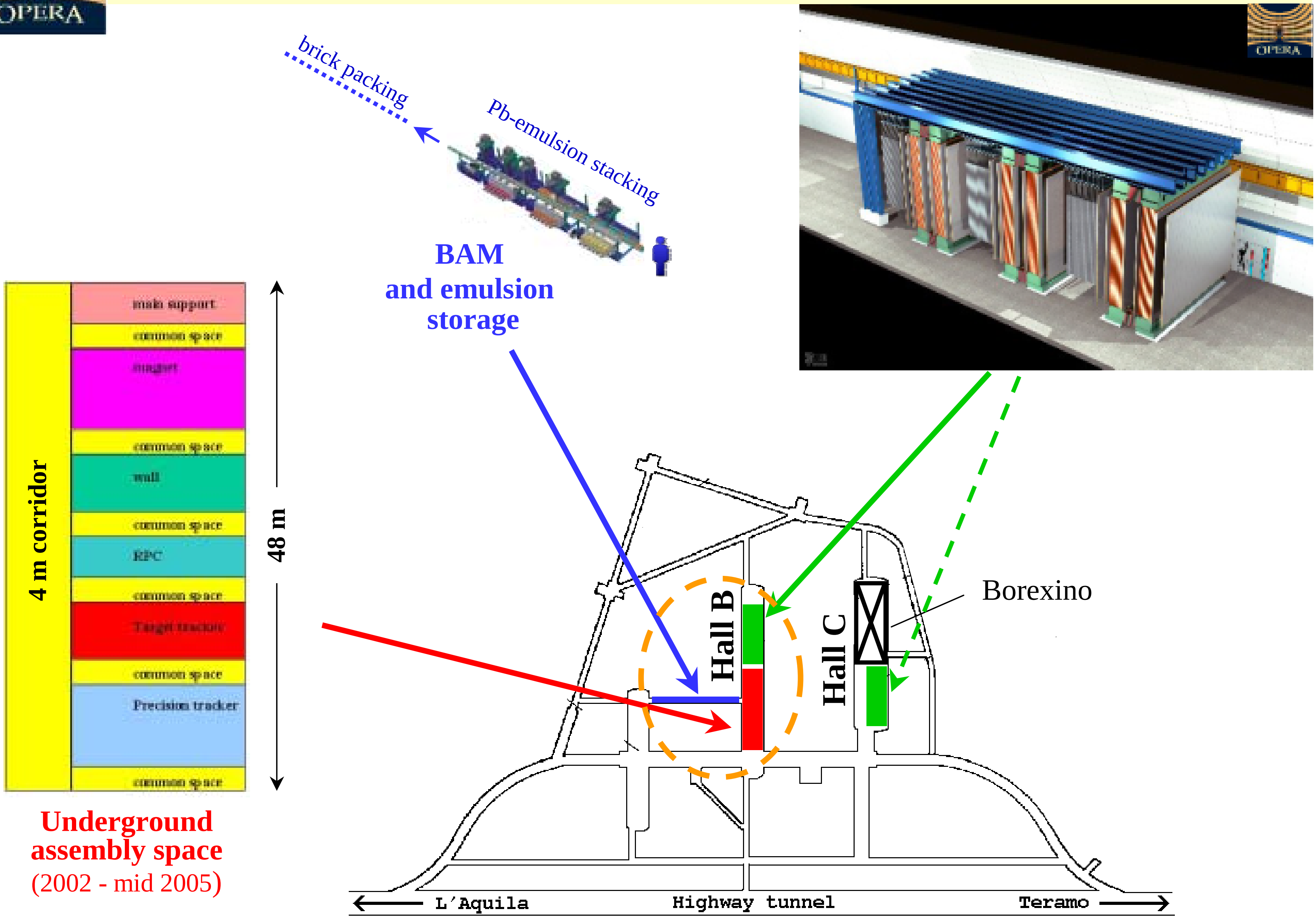
⬇

“Challenging” schedule

Starting dates

2002	Installation
2004	Filling with emulsion bricks
2005	Data taking

in Hall B: detector close to BAM and to assembly space



Hall B or Hall C ? Our answer is obvious: Hall B

- **Large detector components are assembled <u>in Hall B</u>**
  - **OPERA in Hall C** $\rightarrow$ <u>transportation</u> of large and delicate components
    <u>load/unload</u> transportation platforms
  - **OPERA in Hall B** $\rightarrow$ direct installation using the crane in the hall
- **Brick are produced in "Bypass" <u>near Hall B</u>**
  - **OPERA in Hall C** $\rightarrow$ <u>transportation</u> of ~ 1000 bricks (~8 ton) /day through hall A or B
  - **OPERA in Hall B** $\rightarrow$ direct access to Hall B
- **Counting room is already available <u>in Hall B</u>**
  - **OPERA in Hall C** $\rightarrow$ <u>interference</u> with detector installation&commissioning

    (A counting room on pillars above the corridor, also used for crane loading restricts the installation of large detector components)

<u>If OPERA in Hall C</u>:

practically impossible to be fully installed at beam start-up in 2005

Conclusions

➢ Achieved

- Studies and construction of full scale prototypes
- Detector design being finalised
- Progress in automatic scanning
- Detection efficiency improved since CNGS approval

➢ Expected signal

- Lower Δm^2 of SK best fit: oscillation rate reduced by a factor of 2
- In a five year run: 10.8 signal and 0.75 background events

➢ Detector construction

- Large and complex detector, with a “challenging” schedule
- Now the transition to the construction phase
- Lower oscillation rate $\Rightarrow$ larger effort on various aspects
- Strong technical support required also in terms of human resources